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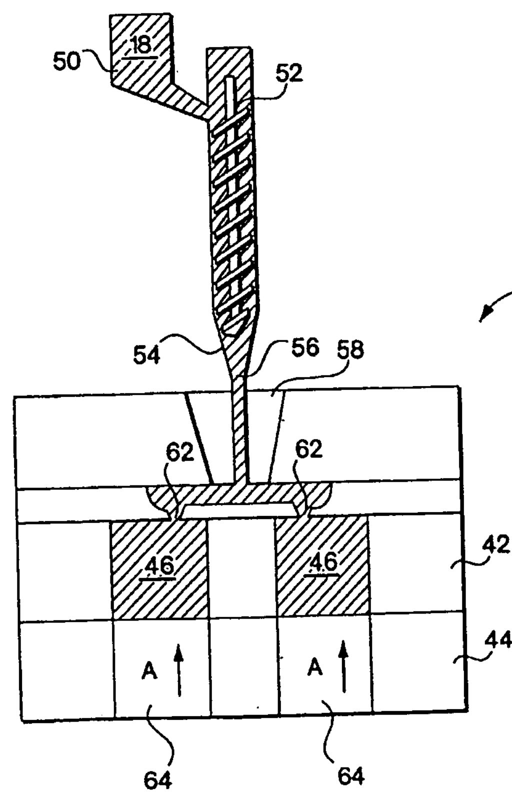
(54) Title: METHOD AND APPARATUS FOR PRODUCING SEMICONDUCTOR PREFORMS

(57) Abstract

Processes and molds useful for performing epoxy mold compounds are disclosed. The molds and processes reduce cycle time and compound waste by maintaining mold compound to be injected in a plasticized state during multiple molding cycles.



METHOD AND APPARATUS FOR PRODUCING SEMICONDUCTOR PREFORMS

Field of the Invention

This invention relates to equipment and processes for producing preforms used to encapsulate electrical or electronic devices. More specifically, the invention relates to improved processes and equipment for efficiently producing relatively high density epoxy mold compound preforms useful for encapsulating devices such as integrated circuits.

Background of the Invention

Modern electrical and electronic components typically take the form of an electrically functional component encapsulated in plastic. For example, coils or capacitors may be encased in a wide variety of inexpensive thermosetting or thermoplastic materials, while high performance integrated circuits typically are encased in high performance epoxy mold compounds such as the SMT Plaskon-brand series of electronic mold compounds (EMC's) available from Plaskon Electronic Materials, Ltd. of Singapore.

While plastic used to encapsulate such components may be provided in a granular form or liquid, component manufacturers, and particularly semiconductor component manufacturers, prefer that EMC's be provided in the form of a preform. A preform typically is cylindrical in shape and provided to a semiconductor manufacturer in a weight and dimension particularly suited for use in the manufacturer's molding equipment. At the manufacturer's site, a device such as a semiconductor die is placed in a mold and the preform is heated to plasticize the EMC, allowing the EMC to encapsulate the device. The molded component then is allowed to cure, ejected from the mold, and finished as required by the manufacturer's customer.

The conventional method of making preforms is to compress a mixture of resin, fillers and other EMC additives at high pressure in tableting equipment. This tableting process is not preferred because the tableting presses are subject to substantial wear from the several tons per square centimeter pressures required by the process. Additionally,

preforms formed by this method have been known to exhibit voids and other quality problems which may carry over to devices molded using those preforms. An example of one such tableting process can be found in U.S. Patent No. 4,554,126 to Sera.

An improved method for manufacturing EMC preforms can be found in U.S. Patent No. 5,804,126, the disclosure of which is incorporated by reference and assigned to the assignee of the present application. In the process disclosed in US Patent No. 5,804,126, preforms are prepared by warming thermosetting resin to form a warm melt without substantially curing the thermosetting resin, injecting the warm melt into a mold without substantially curing the resin, cooling the warm melt in the mold to form a solidified preform, and then is removing the cooled, uncured preform from the mold.

The process of the aforementioned patent is preferred to a tableting process because the resultant preforms have superior quality. They are characterized by the absence of voids and have densities of at least 95%. In addition, the preforms exhibit a uniform color, are dust free, and substantially free of other forms of contamination that may prove detrimental to devices molded from the preforms.

Despite the high quality of performs produced by the process described in U.S. Patent No. 5,804,126, we have identified certain aspects of the process that can be improved. In particular, that process can exhibit an undesirably high yield loss because thermoplastic material in the channels leading to the preform mold chamber must be discarded each time a preform is molded. This waste occurs because it is not possible to recycle thermoset material for reuse once the material has been plasticized and eventually solidified.

In addition to material waste, the time required to remove the thermoset material from the channels leading up to the mold slows manufacture, rendering the process less efficient than it otherwise might be.

Additionally, preforms manufactured by the process described in U.S. Patent No. 5,804,126 can require a multistep process to remove waste material and preforms from the mold and to degate the preforms. It would be preferred to eliminate the need for one or more steps from that process to reduce cycle time and cost.

What is needed is a preform manufacturing process that provides uniform, high density, degated preforms, but with reduced waste and increased preform throughput rates when compared to the injection molding process disclosed in U.S. Patent No. 5,804,126.

Summary of the Invention

The present invention provides improved preform throughput rate and decreased EMC waste by employing novel thermoplastic molding techniques.

By maintaining certain regions of the preform injection mold within critical temperature ranges, material in mold channels that must be discarded from conventional molds each time a preform is made can instead be maintained at a temperature sufficient to allow that material to be injected into the mold during the next cycle. This substantially reduces material waste and cycle time. Eliminating waste material removal results in additional process efficiency because process steps and equipment required to remove waste material are eliminated.

Furthermore, we have found that the mold designs in accordance with our invention can automatically degate solidified preforms when the mold is opened, thereby increasing efficiency of the molding process by eliminating the need for an additional degating process step.

Brief Description of the Drawings

FIG. 1 is a simplified side elevation view of a conventional injection mold useful for producing EMC poforms.

FIG. 2 is a simplified side elevation view of an improved mold in accordance with our invention.

FIG. 3 is a top view of the upper surface of a mold core portion in accordance with the present invention illustrating insulating voids present on the upper surface of the mold core portion.

FIG. 4 is a side elevation view of the mold core portion of FIG. 3 taken s along line 4-4 of FIG. 3 showing additional detail of the insulating voids.

FIGS. 5a, b and c illustrate where the mold of FIG. 1 parts during a preform manufacturing operation.

FIGS. 6 a and b illustrate where the mold of FIG. 2 parts during a preform manufacturing operation.

Detailed Description the Preferred Embodiments

FIG. 1 is a simplified view of a conventional mold of a type useful for manufacturing a pair of EMC preforms by an injection molding process.

Mold 10 includes a cavity mold half 12 and a core mold half 14 which, when placed together, cooperate to form cylindrical void areas 46 which are filled with mold compound during the preform manufacturing process.

Mold compound is injected into mold 10 by placing an EMC mix 18 of granular resin, filler and any other desired additives in a hopper 20, and then employing a heated screw 22 which is utilized to plasticize mix 18 and force plasticized mix 18 through a nozzle 24 into mold 10.

EMC mix 18 is forced first through a sprue 26 and through a plurality of runners 28 (located in runner plate 30) and then through gates 32 into void areas 46. Void areas 46 typically are chilled to prevent any significant curing of EMC mix 18 in voids 16, as curing of EMC 18 would render preforms made of EMC mix 18 unsuitable for subsequent semiconductor molding operations.

After the preform is formed in mold 10, mold halves 12 and 14 are separated, and ejector pins 34 having a cylindrical shape and a cross section of substantially the same diameter as voids 16 move upward in the direction of arrow A to force the injection molded Drcforms from voids 16.

FIG. 2 illustrates an injection mold 40in accordance with the present invention which can substantially reduce waste and cycle time in preform manufacturing processes. Mold 40 includes a cavity mold half 42 and a core mold half 44 which, when placed together, cooperate to form cylindrical void areas 46 which are filled with mold compound during the preform manufacturing process.

Mold compound is injected into mold 40 by placing an EMC mix 48 of granular resin, filler and any other desired additives in a hopper 50, and then employing a heated screw 52 to plasticize EMC mix 48 and force plasticized EMC mix 48 through a nozzle 54 into mold 40.

Mold halves 42 and 44 typically are held together in a clamping unit (not shown) having a clamping force of from about 50 to 400 tons.

EMC mix 48 is forced through a sprue 56 which is surrounded by heater elements 58. Heater elements 58 maintain sprue 56, runners 60, gates 62 and EMC mix 48 passing through sprue 56, runners 60 and gates 62 at an elevated temperature. Mold core half 44, however, is maintained at a chilled temperature to cause a large temperature differential between heated cavity mold half 42 and chilled mold half 44. When EMC 46 in chilled mold half 44 has solidified, mold halves 42 and 44 are opened (as described in detail in connection with FIG. 6), and ejector pins 64 are used to eject preform EMC mix 48 in the same manner as described in connection with FIGs. 1-2.

FIG. 3 illustrates the presence of insulating voids 62 on the upper surface 64 of chilled mold half 44. Voids 62 provide thermal insulation between mold halves 42 and

44 which helps mold 40 maintain the desired temperature differential between mold halves 42 and 44. The size and shape of insulating voids 62 is non-critical, and should be selected to maintain the desired temperature differential between core halves 42 and 44 under routine operating conditions. Additional detail of insulating voids 62 can be seen in the side view of FIG. 4 taken along line 4-4 of FIG. 3.

Because EMC mix 48 in sprue 56 and runners 60 is maintained at an elevated temperature at all times, EMC mix 48 never solidifies, and therefore does not need to be removed. This results in substantial waste reduction and cycle time reduction.

FIGS. 5 and 6 further illustrate the advantages of our improved mold over a conventional mold.

FIG. 5a-c are sides view of the mold of FIG. 2 which illustrate where mold 10 parts during preform manufacturing operations. Referring first to FIG 5a, mold 10 includes mold division lines PLA and PLB where the mold is separated during operation. FIG. 5b shows that the first step in removing molded preforms from mold 10 is to separate runner plates 30 along mold division PLA to facilitate removal of waste material from sprue 26. Referring to FIG. 5c, mold 10 next is separated in a second step along mold division line PLB to de-gate solidified preforms located in voids 16 and to facilitate removal of waste material from voids 16.

FIGS. 6a and 6b illustrate the simplified process of removing preforms from molds in accordance with one embodiment of our invention. Mold 40 includes a single mold division PLC adjacent the upper edge of cavity half 42. Removing preforms from mold 40 requires only separating mold 40 along mold division line PLC as shown in FIG 6b. This single step automatically degates the preforms in voids 46 and permits the preforms to be removed from mold 40. Because EMC mix 48 in sprue 56 and runners 60 remains plasticized, there is no need to remove that material as waste material. As can be seen by comparing the sequence of FIGS. 5 a-c to FIGS. 6a and b, a process step has been eliminated, and material waste has been minimized, by using heated molds in accordance with our invention.

It should be noted that ejector pins 64 preferably are the same cross-sectional size and shape as the cross section of the desired preform as defined by a geometric PLANE D parallel to parting line PLC in FIG. 6 (b). This provides the added advantage of being able to adjust the length of a preform prior to injecting plasticized epoxy molding compound into cylindrical void areas 46 by adjusting the depth of pin 64 along an axis of symmetry AS perpendicular to the void's cross section. Ejector pins having a smaller

cross section than the perform can be used with the invention if this added advantage is not required.

Preferred operating temperatures for cavity mold half 42 typically range from 50 to 90^{0}C, depending on the particular thermosetting resin to be plasticized. The exact temperature must be optimized in relation to all other conditions to obtain a warm, flowable melt without substantially curing the resin. It is important to control the temperature and pressure of the process so that the thermosetting resin does not substantially cure in the warm melt or in the resultant preform. Otherwise, the preform will not be useful for its intended purpose.

Nozzle 54 preferably is heated to a temperature of about 5 to 10 ^{0}C 10 higher than the temperature in the region of screw 52. The temperature of mold half 42 can be obtained by any of a number of heat transfer means known in the art including the direct application of heating fluids to an exterior surface of the mold half, the passing of liquid or gaseous heat exchange fluids through channels in the mold, or by including heater elements such as an electric heating element in or adjacent to mold half 42. The heating means will heat runners 60 and sprue 56 at a temperature sufficient to maintain the EMC in a plasticized state. Typically, the EMC temperature required will be between about 50 and 90 ^{0}C.

The invention requires that a mold portion containing the cavity for shaping the material into the preform be maintained at a lower temperature than the heated mold portion containing the plasticized material that will be forced into the cavity. Preferred operating temperatures for EMC typically will range from 70 to 80 ^{0}C. Mold cavity half 42 typically is maintained at a lower temperature by cooling mold core half 44 with water chilled to about 5 ^{0}C. It is preferred to maintain a temperature differential between the heated mold portion containing the plasticized material and the mold core half 44 of at least about 50 ^{0}C, and most preferably between about 65 to 75 ^{0}C. Cavity mold half 44 can be cooled or chilled by any means know in the art such as the direct application of chilling fluids or the passing of heat exchange fluids through channels in mold half 44. The preferred cooling method is to use a liquid cooling fluid such as water, antifreeze, or compressed gas, which is in direct contact with mold half 44.

A wide range of thermosetting resins are suitable for preforms prepared in accordance with our invention. For example, the thermosetting resin can be an epoxy resin, a polyester resin, a silicone resin, a thermosetting rubber, a cyanate resin, or

mixtures of the foregoing. Preferred resins are those prepared from cresol novalak epoxy/phenol novalak hardener systems.

The thermosetting resin can be mixed with other materials such as fillers, curing accelerators, release agents, flame retardants, and surface-processing agents. It is preferred, but not required, that these materials be mixed before being plasticized in injection system. These other materials are well-known in the art, and usually include a filler comprising one or more sizes and shapes of silica. These additional materials usually constitute at least 50%, and often up to 85%, of the EMC mixture by weight. The thermosetting resin is usually mixed with these additional materials either prior to or during the warming step.

Preforms formed in accordance with our process preferably range in weight from about 10 to 1000 grams, and more preferably from about 40 to 600 grams. Voids 46 are sized to produce preforms of the desired shape and size. Cylindrical preforms are preferred for easy injection of plasticized material and removal of preforms, but other shapes are possible. The amount of material injected into voids 46 is controlled by the travel of screw 52 during the injection cycle. Typical cycle times from injection of plasticized EMC until ejection of a preform range from about 25 to 30 seconds, with the determining factor being the amount of time it takes for the plasticized EMC to become dimensionally stable enough to eject from voids 46 without losing the desired preform shape.

The pressure exerted on the plasticized resin during the cycle typically is between 300 and 700 bar. After injection, plasticized material is maintained tinder pressure higher than the melt pressure to prevent plasticized material from flashing and also to cool and render shape to the plastic in the mold which, contrary to conventional thermosetting molding, is kept cold, at between 10 and 25° C.

One injection molding press can serve multiple mold cavities in order to increase production rates. Typical molds will include between about 20 and 50 voids 46.

The preforms resulting from the invention typically have densities S consistently above 95% of theoretical density, which is a measure of void imperfections. L/D (length over diameter) ratios of from 1 to 5 are possible, with L/D ratios from between about 1 and 2 being preferred. The preforms have been found to exhibit good resistance to breaking and chipping, are of uniform color, are dust free, and have more consistent spiral flow values in that variations of less than 0.75 inches are easily achieved. Flash

and bleed values for low viscosity products of 2-8 mm through a 6 micron gate are readily achieved, as are minimal weight variations.

Additionally, because the improved mold and process eliminates the need for process steps associated with discarding runner and sprue material, the possibility for contamination and moisture uptake into the preforms is reduced.

We claim:

1. A process for preparing preforms useful for encapsulating electronic and electrical components comprising the steps of:

warming a mixture comprising a thermosetting resin to form as plasticized melt without substantially curing the thermosetting resin;

injecting the plasticized melt into a mold having a void located therein for shaping injected thermosetting resin into a preform having a shape generally corresponding to the shape to the void;

maintaining a first portion of the mold through which plasticized melt passes to the void at a temperature sufficient to maintain the melt in a plasticized state;

maintaining a second portion of the mold which includes the void at a temperature lower than the temperature of the first mold portion, thereby cooling the plasticized melt in the mold to form a solidified preform;

removing the preform from the mold without curing the thermosetting resin.

2. The process of Claim 1 further including the step of maintaining the second mold portion at least 65 ^{0}C lower than the temperature of the first mold portion.

3. The process of Claim 2 performed three or more times while maintaining a temperature differential between the first and second mold portion temperatures of at least 50 ^{0}C.

4. The process of Claim 1 wherein the second mold portion is cooled by contacting the second mold portion with chilled water.

5. The process of Claim 1 wherein the first portion of the mold includes a spruc and runner and wherein the process further includes the step of heating the first mold portion to maintain epoxy mold compound contained in the runner and spruc in a plasticized state.

6. The process of Claim 1 further including the step of simultaneously heating the first mold portion and chilling the second mold portion to maintain a temperature differential.

7. The process of Claim 6 further including the step of maintaining the temperature differential between the first and second mold portions between about 65 and 75 ^{0}C.

8. The process of Claim 7 further including the step of degating a preform by separating the first and second mold portions along a parting line located adjacent the mold void to degate a preform contained in the void.

9. The process of Claim 1 wherein the mold has a parting line and where the void has a cross sectional shape and size defined by a plane cutting through the void parallel to the parting line, and further including the step of ejecting the preform from the void by inserting an ejector pin having the same cross-sectional shape and cross-sectional size as the void into the void.

10. The process of Claim 9 wherein the void has an axis of symmetry perpendicular to the void's cross section and further including is selecting the position of the ejector pin in the void along the axis of symmetry prior to injecting plasticized epoxy molding compound to determine a length of the preform along the axis of symmetry.

11. A mold for producing preforms of thermosetting material useful for encapsulating electrical and electronic components comprising:

a heated first mold portion for maintaining thermosetting epoxy mold compound contained therein in a plasticized state;

a second mold portion separable from the first mold portion along a mold division line, the second mold portion including a void for receiving plasticized mold compound from the first mold portion; and

a mechanism to maintain the second mold portion at a lower temperature than the first mold portion.

12. The mold of Claim 11 wherein the second mold portion is maintained at a temperature of at least 50 ^{0}C less than the first mold portion.

13. The mold of Claim 11 further including an insulator for maintaining a temperature differential between the first and second mold portions.

14. The mold of Claim 13 wherein the insulator is a plurality of voids formed between the first and second mold portions.

15. The mold of Claim 11 wherein the first mold portion includes a heated element for heating the first mold portion.

16. The mold of Claim 11 wherein the first mold portion includes heat exchange channels for circulating heated liquid or gaseous fluids within the first mold portion to heat the first mold portion.

17. The mold of Claim 11 wherein the second portion half includes heat exchange channels for circulating liquid or gaseous fluids within the second mold half to cool the second mold portion.

18. The mold of Claim 11 wherein the second mold portion includes a heat transfer surface for directly contacting a heat exchange fluid with the mold to cool the second mold portion.

19. The mold of Claim 12 further including at least one void formed is between the first and second mold portions to insulated the first mold portion from the second mold portion, a heating element for heating the first mold portion, and a cooling means for cooling the second mold portion.

20. The mold of Claim 19 wherein the cooling means is a heat transfer surface located on an outer surface of the second mold portion which permits the second mold portion to be cooled by direct contact of the heat transfer surface with a heat transfer fluid.

21. The mold of Claim 11 wherein the first and second mold portions define a mold division line located adjacent the mold void at one end of the mold void to degate a preform contained in the void when the mold portions part.

22. The mold of Claim 11 wherein the mold has a mold division line and where the void has a cross sectional shape and size defined by a plane cutting through the void parallel to the mold division line, and further including an ejector pin having the same cross-sectional shape and cross-sectional size as the void.

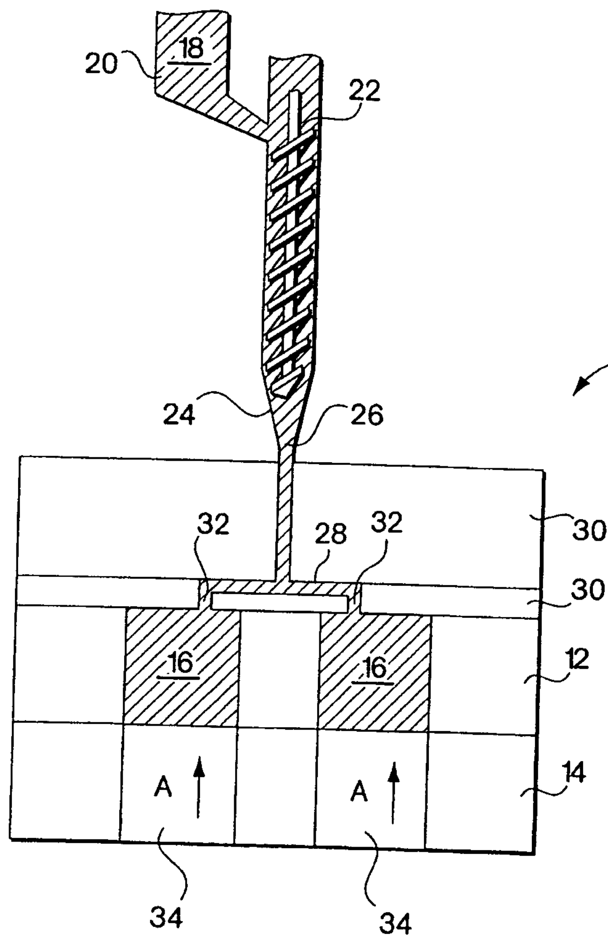


Fig. 1

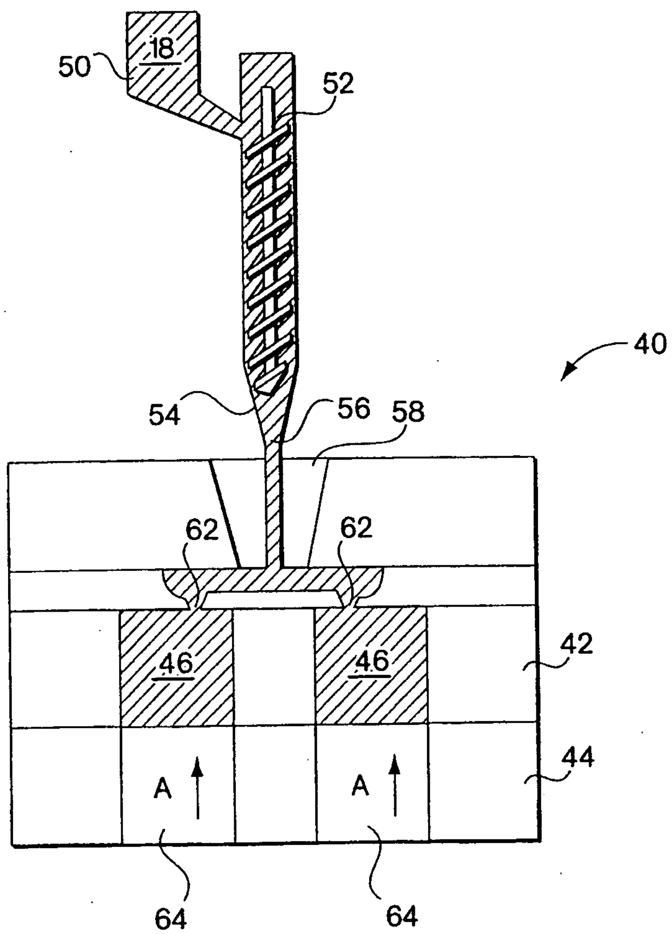


Fig. 2

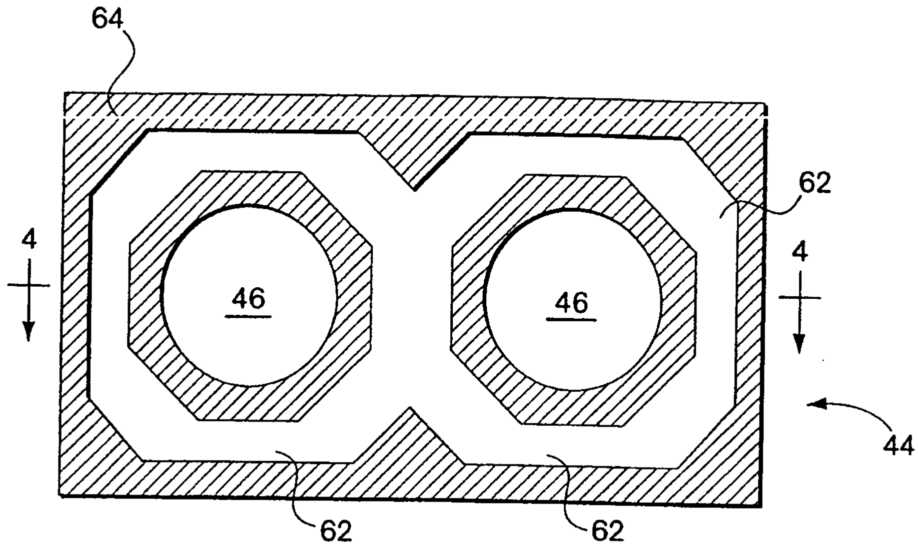


Fig. 3

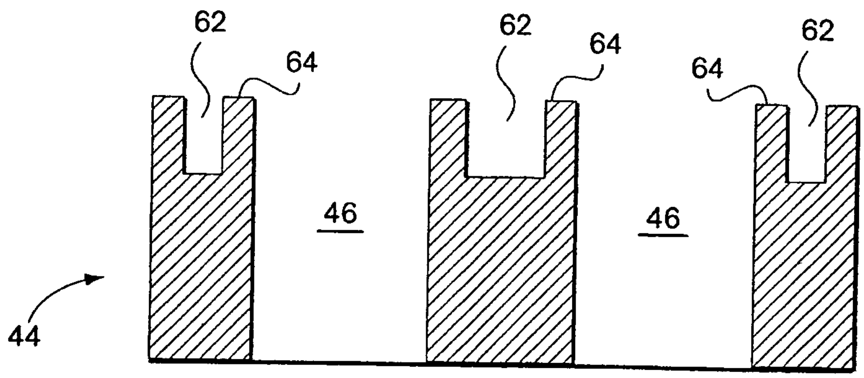


Fig. 4

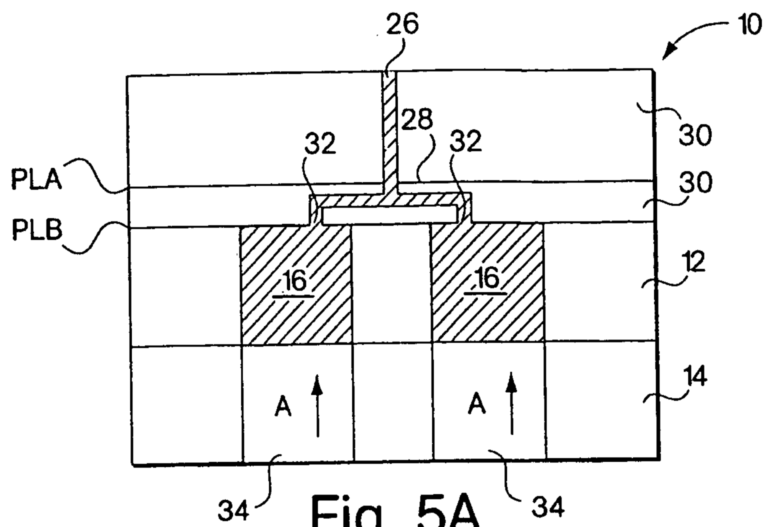


Fig. 5A

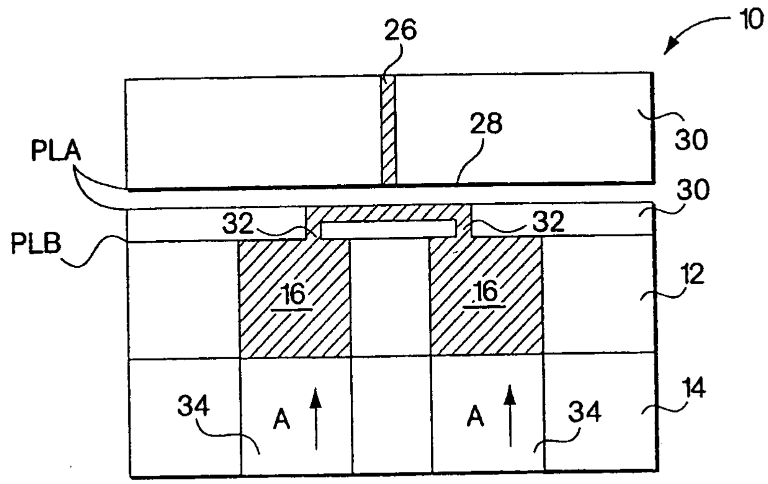


Fig. 5B

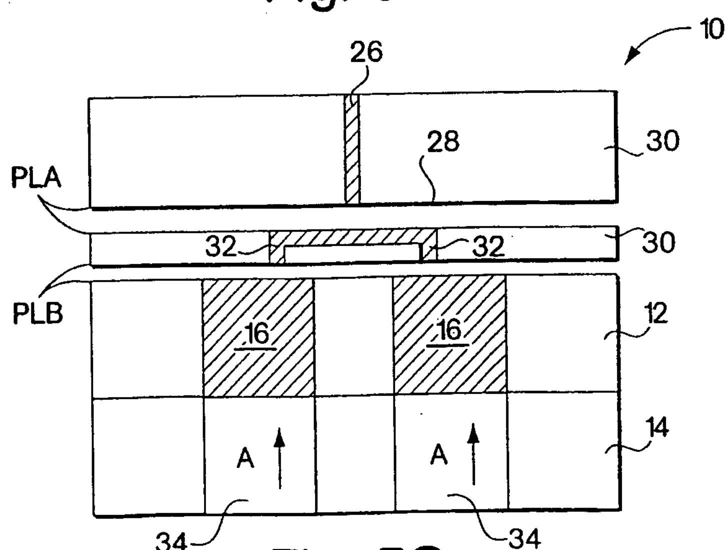


Fig. 5C

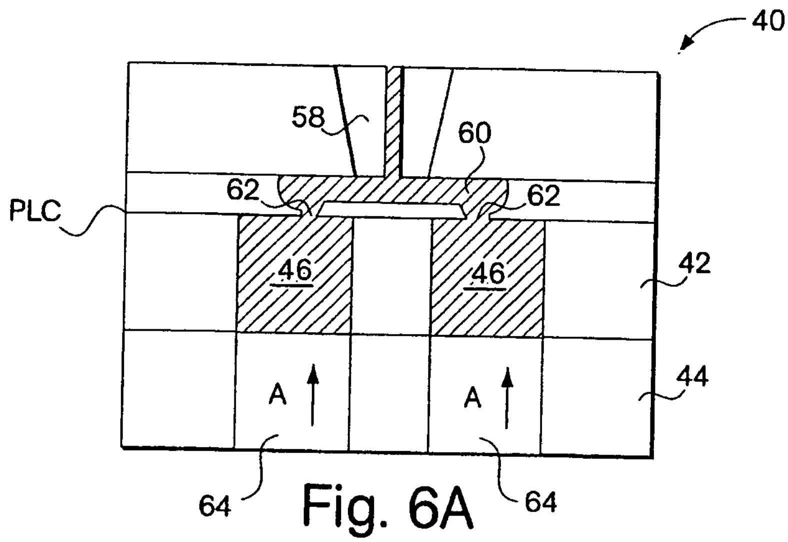

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Fig. 6A

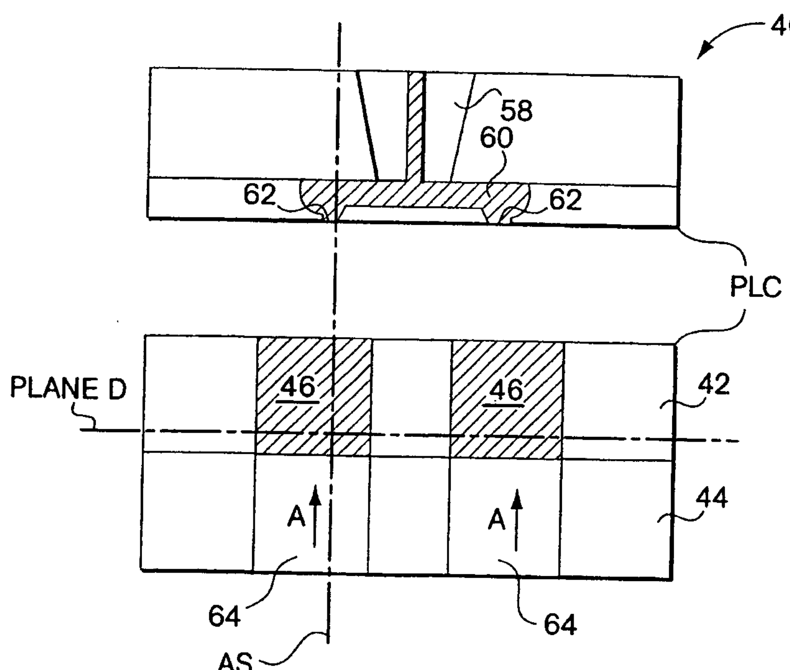
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Fig. 6B

INTERNATIONAL SEARCH REPORT

Interr ...nal Application No
PCT/SG 00/00021

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B29C45/46 B29B11/08 H01L21/56

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B29C B29B H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 810 248 A (MITSUI PETROCHEMICAL IND) 3 December 1997 (1997-12-03) page 3, line 6 - line 8 claims 1,2; figure 3	1,11
A	US 4 309 379 A (DANNELS W ANDREW ET AL) 5 January 1982 (1982-01-05) column 2, line 49 -column 3, line 11 abstract; figure 5	1-22
A	US 4 996 170 A (BAIRD JOHN) 26 February 1991 (1991-02-26) abstract	1-22
A	US 4 554 126 A (SERA MICHITOSHI) 19 November 1985 (1985-11-19) cited in the application abstract	1-22

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
4 July 2000	13/07/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Clarke, A

1

INTERNATIONAL SEARCH REPORT

Interr nal Application No
PCT/SG 00/00021

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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